STATUS OF THE IUCF COOLER INJECTOR SYNCHROTRON

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Abstract

Construction of a 2.24 T-m, rapid-cycling booster synchrotron is nearing completion at IUCF. Designed to accelerate protons to 220 MeV, it will replace the k200 isochronous cyclotron as an injector of polarized light ion beams (p, d) into the Indiana Cooler. CIS (Cooler Injector Synchrotron) will fill the Cooler to about 10^{11} protons in a few seconds for research. At 30 months into the construction program, all major ring elements are fabricated, assembled, installed and in some cases, commissioned. Ring strip injection and accumulation studies began in March, 1997, ramping studies will start in June, 1997 and Cooler injection studies are planned for late 1997. The status of the construction project and initial beam injection and commissioning results are presented.

1 INTRODUCTION

At the 1995 U.S. PAC, IUCF announced the funding ($2.0M NSF, $1.5M Indiana Univ, 8/94) of and presented major system design and performance goals for a 2.24 T-m booster synchrotron [1, 2, 3, 4, 5] to replace the k200 cyclotron as an injector of polarized ions (p,d) into the Indiana 3.6 T-m electron cooled storage ring [6]. The new injector complex, shown in Fig. 1,

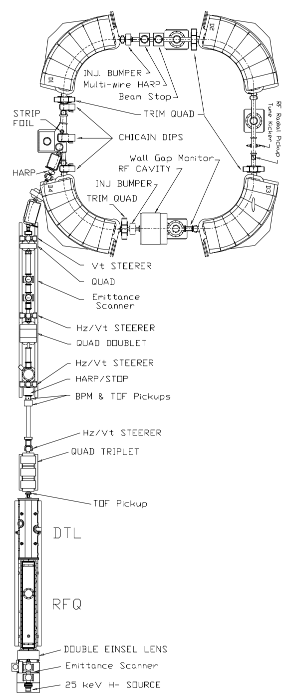

Figure 1: The CIS synchrotron and injection system.

consists of a pulsed, polarized negative ion source (1 mA peak) and 25 keV LEBT, a 7 MeV H^- linac pre-injector, a 9 m long injection beam line, and a rapid cycling (1–5 Hz) 220 MeV proton synchrotron. The lattice chosen for this ring operates below transition, relies on dipole edge angle focusing, and has small dispersion (1.7m) and momentum compaction values (0.62). The small ring circumference (17.37m) presented several accelerator component design challenges. The laminated main dipole magnets (1.27 m radius, 90° bend and 1.7 T maximum field) and the fast extraction kicker and pulse forming network (17 mrad bend, 1m insertion length and 50 nsec risetime) were two such challenges. Several contributions to this conference [7, 8, 9, 10, 11, 12, 13] report on these and other **CIS** accelerator systems completed during the last 24 months. IUCF accelerator operations for research were suspended on November 27, 1996 to install the Linac and assemble the **CIS** ring. Injection and accumulation of 10^{10} protons in the ring was first demonstrated on March 26, 1997. The status of the project, including the initial beam strip injection and accumulation results, is summarized below.

2 RING ASSEMBLY

As the shutdown began, the main dipole and smaller ring magnetic elements were fabricated, field mapping was nearing completion, the Linac pre-injector was undergoing final testing at the factory, and the accelerator vaults and utilities were ready for ring assembly. An unpolarized H^- ion source and 25 keV LEBT was built and the ring injection beam line was assembled and awaiting both the delivery of the Linac and assembly of the ring. The unpolarized source was built from in-house spare parts so that Linac and CIS ring beam development could proceed in parallel with construction of a polarized H^-, d^- source to replace it. For the studies reported here, it routinely delivered 0.4 mA (peak), 25 keV H^- beams, pulsed (50–300 us) at 1–5 Hz with an emittance ($<0.5\pi$ mm-mrad norm.) and convergence (125 mrad Hz & Vt) well matched to the specified RFQ input requirements.

The Linac was delivered in Dec. ’96 and evening beam commissioning studies began in Jan. ’97 and continued in parallel with daily ring assembly work throughout the 4 month long shutdown. The ring was assembled in its final design configuration except that the extraction kicker and 12° vertical Lambertson magnets were not installed. Their allocated space was used for temporary diagnostic elements (multi-wire HARP, beam stops & emittance scanners) to facilitate the strip injection and accumulation studies. The 4000A ramping main dipole magnet power supply, obtained surplus from FNAL, was completed and initial ramping tests were conducted using the main dipoles. The ferrite tuned rf accelerator cavity was also installed in the ring. The ring vacuum system, including welded SS dipole vacuum chambers (1mm wall, 5 cm by 10 cm elliptical cross section) incorporating eddy current sextupole correction coils, was completed and evacuated to an average pressure of $<$0.3 μTorr on March 20, 1997. All ring magnets except the 4 trim quads and the 2 injection bumper magnets were powered and operable via the CIS VISTA control system.

3 RING BEAM DEVELOPMENT RESULTS

Commissioning of the Linac, a commercial 425 MHZ, 3 MeV H^- RFQ coupled directly to a 4 MeV H^- DTL, is reported elsewhere in these proceedings [8]. Briefly, Linac beam transmission (80%), and the 7 MeV H^- beam horizontal emittance ($\epsilon_n < 1.0\pi$) and focussing properties meet the manufacturers guaranteed performance. The injection beam line matches this beam to the optics requirements (*MAD*) at the first ring dipole entrance. Fabricated largely from surplus equipment, it begins with a strong (17 T/m) quad triplet that produces a 6 mm dia. waist at the gap of a 425 MHZ debuncher located 2.5m down stream of the Linac. For these tests, the unfinished debuncher was replaced with a multi-wire HARP [12] to measure Linac transmission and beam profiles. A 6 mm FWHM diameter double waist was achieved here using the calculated (*TR3D*) quad triplet run values, verifying the factory Linac optics predictions. Transmission through the remainder of the 9m beam line to the injection stripper foil is also $> 80\%$ using the predicted setup. Of the 400 uA (peak), 25 keV H^- source beam, 320 uA and 250 uA at 7 MeV are transmitted to the HARP following the triplet, and to the stripper foil at injection, respectively. The setup and performance reproducibility of the source, Linac, and beam line is excellent.

Protons are injected into the ring via stripping the 7 MeV H^-beam on a 6.5 mm wide by 25 mm tall 4.5μgm/cm^2 Carbon foil strip fabricated at IUCF. Two bumper magnets located in adjacent straight sections displace the ring equilibrium orbit 20 mm onto the foil during injection. The multi-position foil ladder can be moved transversely to the ring equilibrium orbit to optimize injection. The foil strip improves beam life time and fill rate by increasing the probability that accumulated beam will pass on either side via betatron motion. The calculated foil hit/miss ratio for this configuration is 0.5.

3.1 Ring Strip Injection Performance

Proton beam injection and accumulation were demonstrated at both 3 MeV (RFQ only) and 7 MeV (RFQ + DTL). The action of the missing bumpers was simulated using the ring dipole trims to produce the local orbit bump that displaces the equilibrium orbit onto the carbon foil strip. Injected and accumulated beam is observed on ring dipole entrance and exit BPM's, a Wall Gap Monitor and a multi-wire HARP. The HARP, located between dipoles 1 and 2, is used to view 1st turn injected beam and to close the circulating beam orbit through the first 10 turns or so. A beam stop just behind the HARP measures the strip injection efficiency. Orbit centering and accumulation are optimized using the BPM's and WGM with the HARP and stop removed. 7 MeV proton injection and accumulation profiles, measured with the dipole 2 exit BPM (BPM4), are shown in Fig. 2.

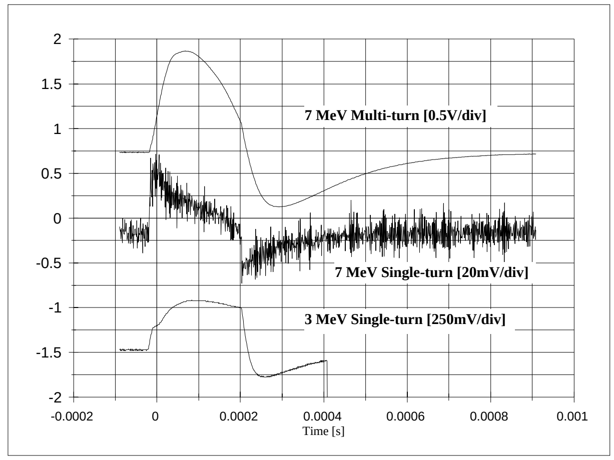

Figure 2: BPM and WGM FET Accumulation Profiles

For these measurements, ring vertical steerer 3 was adjusted from its optimum stored beam value to full output current to prevent multi-turn accumulation to view only the injected beam pulse. The injection pulse length of 220 μsec and the r/c time constant of the BPM amplifier input filter are clearly visible in the single- turn profile. The injected proton beam intensity measured on the stop was 250 μA. The accumulated equilibrium intensity gain of 75 was reached in 100 μsec. A maximum of 18 mA (8×10^{10}protons) were accumulated. Stored beam intensity scales with source intensity, hence the accumulation limit is emittance growth rather than space charge dominated.

A similar injection profile for 3 MeV H^- beam injection is also shown in Fig. 2. The 3 MeV H^- beam is obtained by simply turning off the DTL cavity power. For this beam, an intensity gain of 20 was reached in 75μsec, producing 5 mA of stored protons. The irregular shape of the fill rate after the first 50 usec is likely due to poor centering or injection trajectory.

7 MeV beam accumulation was independently observed by measuring the peak voltage induced across the 3.3 Ω impedance of a wall gap monitor with 200 volts of rf on the accelerator cavity. The WGM voltage is shown in Fig. 3 along with a simultaneous BPM4 accumulation profile. The WGM 57 mV (peak-to-peak) corresponds to 8.5 mA of protons captured in the rf bucket. The rf capture is not adiabatic, only about half the injected beam is captured in the rf bucket, so this measurement is consistent with the simultaneous 17 mA BPM measurement shown. Note that beam capture in the rf bucket at 7 MeV begins only 150 usec after injection start and is completed in about 250 usec. First attempts to capture the 3 MeV beam in an rf bucket were

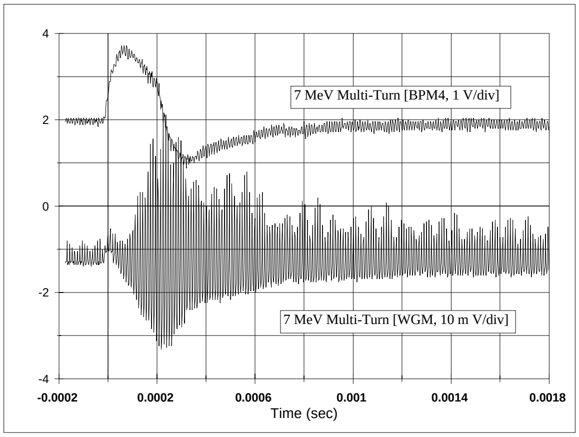

Figure 3: 7 MeV BPM & WGM Accumulation Profiles

not successful, probably because of the short lifetime at this energy. The measured intensity gain and fill rates agree reasonably well with predictions [5]. The 3 to 7 MeV intensity gain ratio (3.5) agrees with calculations, but the measured gains are about a factor of 2.5 smaller than calculated for H^- beams with 1.5% ΔT/T and $1.0\pi\epsilon_n$ on a 4μg/cm2 Carbon foil. The missing injection bumpers prevent storing the beam long enough to obtain accurate centering information from the ring BPM's and the missing 425 MHz beam line debuncher increases energy spread and reduces life time of the accumulated beam. Measurements at 7 MeV show both short (100 usec) and long (295 msec) 1/e lifetime components, indicating that some beam is displaced off the foil via betatron motion or foil and gas scattering induced energy loss. The shorter life time is that expected for beam on the 4.5 ug/cm^2 foil.

Foil longevity has not been a problem. All development runs were made using the same foil, and without the injection bumpers, the injected and accumulated beam remained on the foil continuously. In routine operation, the injected beam will be on the foil for $\leq 200\mu$sec/sec, a duty factor 5000 times smaller than used for these tests. There is no visible sign of foil deterioration.

3.2 Ring Lattice Parameters

CIS ring Hz and Vt fractional tunes with no trim quad current were measured via the traditional knockout procedure to be 0.49 and 0.77 respectively, which are to be compared with calculated values of 0.491 and 0.783. The stored beam long lifetime component (295 msec) was maximized by adjusting the rf cavity frequency to 2.09683 MHz. For the CIS ring design circumference (17.364 m), this corresponds to a proton beam energy of 6.987 MeV. The rf cavity frequency was varied about this optimum until beam was removed from the ring. The measured frequency width of the stored beam was ± 15 kHz, corresponding to $\pm 1.5\%$ energy acceptance.

4 RING COMPLETION SCHEDULE

Work is continuing to install the injection bumpers and complete the ring ramping controls hardware and software. Main dipole power supply commissioning is proceeding and fabrication of the 20 A, 200 V main dipole trim supplies is underway. Beam ramping development should begin in June with the unpolarized H^- beam, and will continue until the annual December IUCF accelerator shutdown. Fabrication and testing of the extraction kicker should be completed in time for ring installation then. The high energy beam line between CIS and the Cooler ring will also be assembled throughout this period. Unpolarized protons from CIS will initially be injected into the Cooler in January, 1998 following this shutdown. Cooler injection will use the existing the stripping path and ferrite kicker in corner 1. Because of the slow rise and fall times of this kicker, only 2 of the 5 Cooler buckets can be filled in this way. At the CIS design goal of 2.5×10^{10} protons/pulse, this should still give 5×10^{10} stored protons in the Cooler.

5 ACKNOWLEDGMENTS

The successes reported here were the direct result of the skill and dedication of the IUCF technical and professional staff, who installed and debugged a 7 MeV RFQ/DTL Linac and assembled the synchrotron ring, after two years of parts fabrication, during a single 4 month shutdown. The shutdown ended with beam injection and accumulation achieved on the 1st attempt on March 26, 1997, just one week after pumping the completed ring to 0.2 μTorr. There is no substitute for experience and cooperation. Supported by Indiana University and National Science Foundation Grants NSF PHY 93-147-83 & 23-423-10.

6 REFERENCES

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